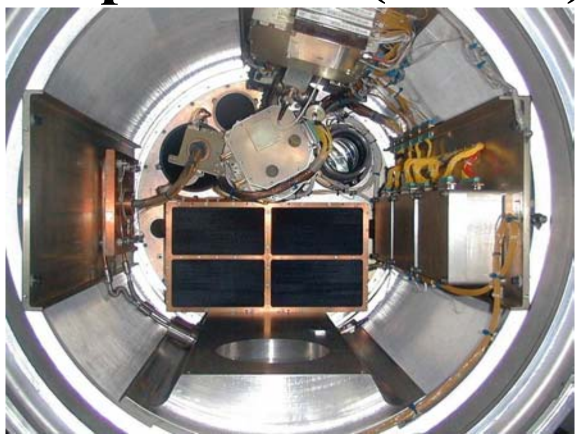
Joint Astrophysical Plasmadynamic Experiment (J-PEX)



Institute acronyms: Naval Research Laboratory (NRL), Lawrence Livermore National Laboratory (LLNL), University of Leicester (UL), Mullard Space Science Laboratory (MSSL)

The Joint Astrophysical Plasmadynamic Experiment (J-PEX) launched successfully on a NASA sounding rocket from White Sands Missile Range, New Mexico, on February 21, 2001. A collaborative effort between the Naval Research Laboratory and Lawrence Livermore National Laboratory in the U.S., and the University of Leicester and Mullard Space Science Laboratory in the U.K., the J-PEX objective was to produce the first high-resolution spectrum of a white dwarf star at extreme ultraviolet (EUV) wavelengths.

White dwarfs are important because they are the end product of evolution for most stars in our galaxy. (For example, our sun will become a white dwarf in about 5 billion years.) White dwarfs are very dense objects, with the mass of the sun squeezed into a volume typically the size of the Earth. During the course of its evolution into a white dwarf, a star will shed some of its mass into the interstellar medium, seeding it with helium and other heavy elements. Since clouds of interstellar matter eventually collapse to form new stars and planetary systems, understanding white dwarf evolution impacts directly on our knowledge of the galaxy and ultimately the universe.

Previous studies of the chemical composition of white dwarf stars have shown that they fall into two distinct types, which appear as separate branches on evolutionary diagrams. One branch has evidence for only hydrogen in its atmosphere, and the second branch is rich in helium. However, it is believed that helium-rich white dwarfs may migrate over to the hydrogen branch. The J-PEX target was the white dwarf G191-B2B, a member of the hydrogen branch.

Earlier observations of the target at visible and far-ultraviolet wavelengths have produced only upper limits to the amount of helium, and measurements by NASA's Extreme Ultraviolet Explorer satellite do not have enough spectral resolution to separate and identify the helium lines from those of heavier elements, such as iron. J-PEX is the first instrument with enough sensitivity and resolution to make such observations in the EUV wavelength range 225-245Å. The final calibrated J-PEX spectrum shows numerous narrow absorption lines of heavy elements superimposed on a continuum. The shape of the continuum provides direct evidence for the presence of ionized helium in the interstellar medium lying between the Earth and this star. Although no photospheric spectral lines of ionized helium were detected directly, a model with a homogenous distribution of elements was fit to the spectrum. This produced a positive indirect measurement of helium in the photosphere, supporting the hypothesis of this white dwarf's origin in the helium branch.

Secondarily, the mission served as a testbed for technical innovations. The primary J-PEX instrument is a high-resolution spectrometer, the design heritage going back to the NRL S-082A instrument flown on *Skylab* in 1973, but with critical improvements. The new spectrometer consists of four identical spherical diffraction gratings that collect light from the star and focus wavelength-dispersed images onto the detector. Each grating forms a separate image, and these spectra were added together during analysis. The gratings were produced using a special technique, unavailable at the time of *Skylab*. This technique, which involves holography and ion-etching, results in superior quality groove profiles and ultra-smooth surfaces. However, the high-quality gratings would be useless without high-reflectance multilayer coatings. The coatings, which were developed at NRL and LLNL, consist of alternate layers of molybdenum and silicon, and enhance grating efficiency by a factor of a hundred.

The NRL AMCORS group (Application of Multilayer Coated Optics to Remote Sensing, W.U. 3641) supports the research and development of multilayer gratings, with the J-PEX gratings being the finest examples to date. Observing times in a sounding rocket flight are typically limited to only 300 seconds above the atmosphere, and therefore high efficiency is necessary to obtain sufficient counts in the spectrum for the desired scientific result. J-PEX grating efficiencies were calibrated at the NRL beamline X24C at the National Synchrotron Light Source, Brookhaven National Laboratory, and resulted in the highest values yet published at EUV wavelengths.

High spectral resolution also places strong demands on detector spatial resolution and efficiency and on instrument pointing. The *Skylab* instrument detector was photographic film of limited sensitivity. J-PEX uses a photon-counting microchannel plate (MCP) detector, which has a high-efficiency Cesium-Iodide photocathode and a state-of-the-art vernier anode of high spatial resolution. In addition, a totally new attitude control system (ACS) was flown on this mission to provide ultra-low thrust levels for payload station-keeping on target, gyros of low drift rate, and a digital control loop. The tiny residual motions from the ACS were tracked by imaging the target star field with a co-aligned optical telescope that included a CCD-readout. The CCD was a spare unit developed by the LLNL for the Lunar Imaging Star Tracker onboard the NRL Clementine spacecraft. The ACS residual motions were separated from the spectrometer detector data to obtain a spectral resolving power in the range 3000-4000.

NASA has approved a proposal to improve the J-PEX instrument and refly it in November 2005 on a sounding rocket with another white dwarf Feige 24 as the target. However, a satellite instrument is needed to make observations more sensitive and numerous than is possible with sounding rockets. Therefore, the J-PEX team is developing a payload concept for the Astrophysical Plasmadynamic Explorer (APEX) to be flown on a NASA Small Explorer Satellite. This powerful instrument would consist of a suite of spectrometers operating at different wavelengths in the EUV. It would be capable of a broad range of study involving a large and diverse set of targets, including stellar coronae and flares, white dwarfs, cataclysmic-variable stars, the interstellar medium, active galactic nuclei, and clusters of galaxies.

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